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Estimating the gross nitrogen budget under soil nitrogen stock changes: A case study for Turkey

Fethi Şaban Özbek *, Adrian Leip

European Commission – Joint Research Centre, Institute for Environment and Sustainability, Italy

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ABSTRACT

The method to estimate the Gross Nitrogen Budget proposed by Eurostat and the OECD was developed under the assumption of no changes in soil nitrogen stock, due to the lack of available data. We estimated the national and regional nitrogen budgets of agriculture in Turkey, calculated according to the recommended methodology at the level of administrative regions. Results suggest that changes in soil nitrogen stocks are likely for some regions. In such cases, the method warns that its estimated indicators (gross nutrient surplus and nitrogen use efficiency (NUE)) are not valid. We propose two different approaches to improve the Eurostat/OECD method, based on assumptions of minimum and maximum NUE, and on regressing the N-input and N-output relationship for regions without obvious soil nitrogen stock changes. Our results show that both approaches give reasonable results for all regions, including those for which the Eurostat/OECD method failed. The results also suggest that soil nitrogen accumulates in some regions and depletes in others. Results give a range of 6–93 kg N ha^{-1} yr^{-1} (mean 35 kg N ha^{-1} yr^{-1}) for the Gross Nitrogen Surplus, and a range of 49–82% (mean 62%) for the NUE.

1. Introduction

Nitrogen (N) is an important source of nutrition for plants. While N deficiency negatively affects plant growth, N surplus (NS) can negatively impact environmental quality and human welfare (Sutton et al., 2013, 2011a,b). These impacts include negative effects on biodiversity, eutrophication, nitrate accumulation in waters, acidification, nitrous oxide emissions (with effects on global warming and the depletion of the stratospheric ozone layer), and risks to human health due to exposure to ozone and particulate matter (Smil, 2011; Sutton et al., 2011a). The agricultural sector is an important source of the N that ends up in ground- and surface waters and the atmosphere (Erisman et al., 2013; Fowler et al., 2013; Sutton et al., 2011a,b). N deficiency, NS and N use efficiency (NUE) in agricultural production are estimated on the basis of agricultural N budgets (e.g. OECD, 2001; Oenema et al., 2003; Leip et al., 2011b; CAPRI, 2013; Eurostat, 2013a). An accurate quantification of the NS and the NUE is crucial in order to identify the possibilities of achieving a resource-efficient agri-food chain (see e.g. EC, 2014, 2011). In Europe, the Gross Nutrient Balance is considered to be a priority agri-environmental indicator (EC, 2006) that is of relevance for both water- and air-quality policies.

The N budget is one of the 28 agri-environmental indicators determined by Eurostat (EC, 2006), and is also one of the mandatory indicators to be compiled within the "Common Monitoring and Evaluation Framework" of the European Commission's Rural Development Policy (EC, 2013). Assessments of N budgets are also carried out by the European Environment Agency (EEA, 2012) and the Organisation for Economic Co-operation and Development (OECD, 2013). N budgets are not only useful as indicators of the environmental pressure of agriculture at the national scale – they also help to improve our understanding of agricultural production systems by quantifying farm, land or soil N-budgets using local and regional data (e.g. Barry et al., 1993; Weissbach and Ernst, 1994; Brouwer, 1998; Grignani et al., 2005; Panten et al., 2009; Leip et al., 2011b). To our knowledge, the NS and NUE have not yet been estimated for Turkey at the regional level.

Eurostat has developed a new methodology for quantifying gross N budgets (Eurostat, 2013b; hereafter referred to as GNB), to be applied by EU countries. This Eurostat GNB methodology, which updates the previous guidelines (OECD and Eurostat, 2007), is based on the land budget method (Leip et al., 2011b). It yields valid results only under conditions where there are no substantial changes in soil N stocks. Data on soil N stock changes are scarce, and no general guidance exists for their estimation at the regional or national level (Eurostat, 2013b).

* Corresponding author at: Via Fermi 2749, TP 266/023, I-21027 Ispra (VA), Italy. Tel.: +39 0332 78 9611; fax: +39 0332 78 9364.
E-mail address: fethi.ozbek@jrc.ec.europa.eu (F.Ş. Özbek).

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The purpose of this study is twofold: first, to develop a method that allows for the estimation of the GNB under conditions of changing soil N stocks; and second, to apply the method to provide the first quantification of N values for the 26 sub-regions of Turkey for the period 2007–2011.

2. Materials and methods

2.1. Study region

According to the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT, 2012a), the total utilised agricultural area (UAA) in Turkey in 2009 accounted for 0.8% of the total agricultural land of the world. The UAA in Turkey is about 20% of the UAA of the European Union (EU), and mineral fertiliser consumption is about 10% that of the EU (FAOSTAT, 2012a). Turkey has high numbers of livestock; for example, it has more goats and poultry than any country of the EU, and the 2nd and 3rd highest numbers of sheep and cattle compared to EU Member States (FAOSTAT, 2012b).

Turkey has four different climate zones: (i) a continental climate in the Interior, Eastern and Southeastern Anatolia regions; (ii) a Mediterranean climate in Western Anatolia and the southern coast of Anatolia; (iii) a Marmara (transition) climate in Istanbul and around the Sea of Marmara; and (iv) a Black Sea climate in the Black Sea region of northern Turkey.

In Turkey, the N removed by crops and fodder per ha (the main output variable in GNB calculations), the mineral fertiliser used, and the number of cattle per ha (the main input variables in GNB calculations) vary considerably between the regions. The differences between these variables are shown in Fig. 1(a)–(c).

2.2. Default GNB methodology (GNB-Eurostat)

We first estimated the GNB on the basis of the methodology suggested by Eurostat (2013b). In the following, we refer to this approach and the derived indicators as GNB-Eurostat, $NS_{eurostat}$, and $NUE_{eurostat}$. A summary of the methodology and data sources for N inputs and outputs used in this study are presented in Table 1. NS is estimated by subtracting the total amount of N contained in the outputs from the total amount of N contained in the inputs, and the result is divided by the reference area A_{ref}. A_{ref} is the total UAA, comprising arable land, permanent cropland, and utilised perment grassland. NUE is estimated as the ratio between the total N in the

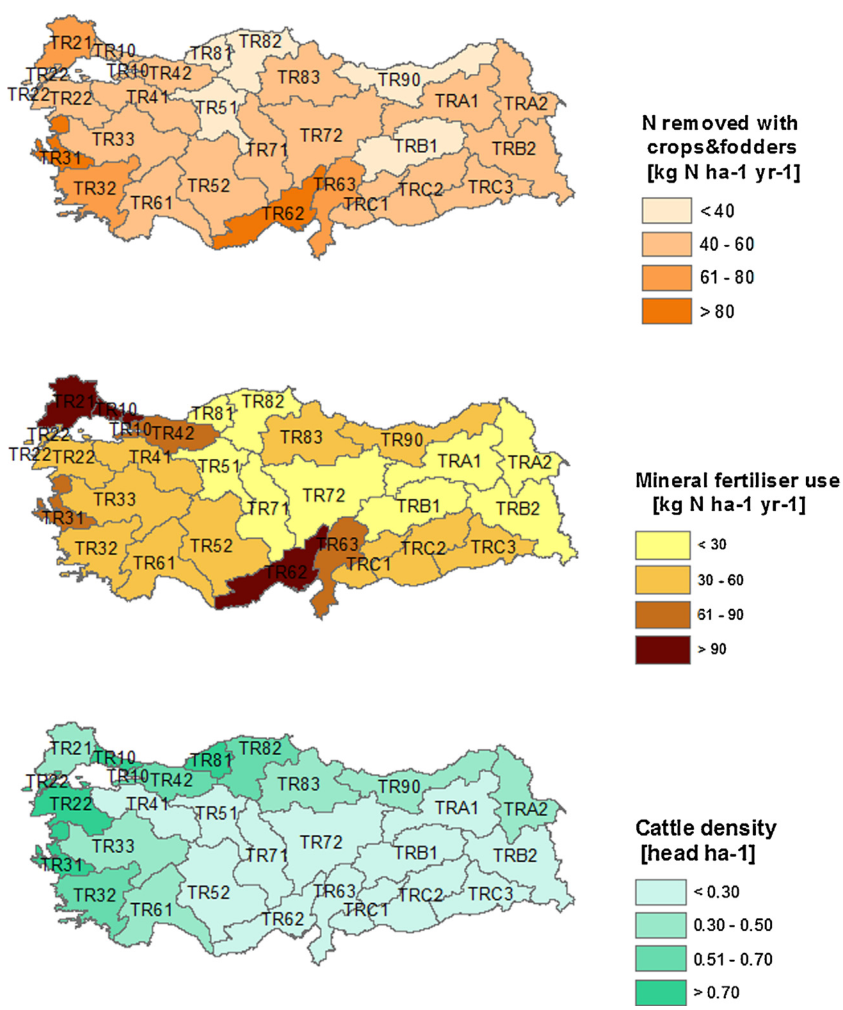

Fig. 1. Selected data required for the quantification of the Gross Nitrogen Budget at the regional scale, averaged over the period 2007–2011: (a) N removed with crops and fodders; (b) mineral fertiliser use; (c) cattle density.
Region codes: TR10: Istanbul; TR21, TR22: West Marmara; TR31, TR32, TR33: Aegean; TR41, TR42: East Marmara; TR51, TR52: West Anatolia; TR61, TR62, TR63: Mediterranean; TR71, TR72: Central Anatolia; TR81, TR82, TR83: West Black Sea; TR90: Eastern Black Sea; TRA1, TRA2: Northeast Anatolia; TRB1, TRB2: Central-east Anatolia; TRC1, TRC2, TRC3: Southeast Anatolia.

Table 1
The inputs and outputs used in GNB-Eurostat, and the methodology and data sources used in estimations.

Inputs and outputs in N balance			Data sources and explanations
Inputs	1) Mineral fertiliser	N_{min}	MFAL (yearly sales data)
	2) Manure production	N_{man}	Number of animals: TurkStat (yearly administrative data), all animal types Excretion coefficients: IPCC 2006, National
	3) Net manure imports/exports, withdrawals, stocks	$N_{\Delta man}$	Negligible[a]
	4) Other organic fertiliser	N_{org}	Negligible[a]
	5) Biological N fixation	N_{BF}	Area: TurkStat (Yearly administrative data); Biological N fixation ratios: Eurostat, crop specific
	6) Atmospheric N deposition	N_{dep}	Turkey atmospheric N deposition: EMEP Reference area: TurkStat Total area: Eurostat
	7) Seed and planting materials	N_{seed}	Cultivated area: TurkStat (yearly administrative data) Nutrient seed input rate: Eurostat, crop specific
	8) Total inputs = sum (1, 2, 3, 4, 5, 6, 7)	N_{input}	$=N_{min}+N_{man}+N_{\Delta man}+N_{org}+N_{BF}+N_{dep}+N_{seed}$
Outputs	9) Crop production	N_{crop}	Crop production: TurkStat (Yearly administrative data), all crop types N content: National, Eurostat, OECD, crop specific
	10) Fodder production	N_{fod}.	Fodder production: TurkStat (Yearly administrative data) Pasture and meadow areas: TurkStat (2001 General Agricultural Census) Yield, consumption: OECD N content: National, Eurostat, OECD, crop specific
	11) Crop residues removed	N_{res}	Crop production, and crop area: TurkStat (Yearly administrative data) Combustion factor, fraction of total area renewed annually, N content of above-ground residues, fraction of above-ground residues removed annually for other purposes: IPCC 1996 and 2006 Guidelines
	12) Stock changes of N in soil	$N_{\Delta soil}$	See Eqs. (4) and (5)[b]
	13) Total outputs = sum (9, 10, 11, 12)	N_{output}	$=N_{crop}+N_{fod}+N_{res}+N_{\Delta soil}$
N surplus	=8–13	NS	$NS=\frac{N_{input}-N_{output}}{A_{ref}}$
N use efficiency	=13/8	NUE	$NUE=\frac{N_{output}}{N_{input}}100$

TurkStat, Turkish Statistical Institute; MFAL, Ministry of Food, Agriculture and Livestock, IPCC, Intergovernmental Panel on Climate Change; EMEP, The European Monitoring and Evaluation programme.
[a] See text (Section 2.2).
[b] See text (Section 2.3).

outputs and the total N in the inputs. The analysis is made using data at the administrative level of NUTS 2 (Nomenclature of Territorial Units for Statistics, sub-regions).

N inputs are mineral fertilisers, N in applied manure and other organic fertilisers, biological N fixation, atmospheric N deposition, and seed and planting materials; the outputs consist of crop and fodder production, crop residues removed from the soil, and stock changes of N in the soil (Eurostat, 2013b).

Mineral fertiliser usage statistics for the NUTS 2 regions are compiled on the basis of sales. These values may be different from the amount of mineral fertilisers that are actually used. N in manure production was calculated by multiplying the number of animals by N excretion coefficients, N_{ex}. For chickens, the national N_{ex} (Eleroglu and Yildirim, 2014) was used; for cattle, sheep and goats, N_{ex} was calculated by multiplying the default N excretion rates given per kg of live animal weight in the IPCC 2006 guidelines (IPCC, 2006) by the national typical animal mass (e.g. Arslan and Bingol, 2013; Anonymous, 2015a,b); for other animals it was calculated by multiplying the default N excretion rates by the default typical animal mass of the IPCC 2006 guidelines.

The number of livestock units utilised for the analysis was based on the surveys carried out at the end of the year. For animals whose population size changes during a year, this might give results that deviate from the average annual population (AAP), which is required for the estimation of total manure excretion. Livestock slaughter statistics, which could be used for a more accurate assessment of AAP, are unfortunately not available at the regional level in Turkey. Using the national poultry slaughter statistics for the year 2011, we estimated a maximum uncertainty introduced in the calculation of NS of 1%, and concluded that the end-of-the-year data were of sufficient quality for the analysis. The number of pigs is negligible in Turkey, so the uncertainty effect of using the end-of-the-year data for pigs in the calculations is also assumed to be negligible.

According to Eurostat (2013b), data on sewage sludge are required and data on other organic fertilisers (e.g. compost, organic leftovers of food industry, digestate from biogas plants) are optional in N budget calculations. While data on the application of other organic fertilisers are not available for Turkey, data from other countries show that this is generally a minor source of N input (on average < 3% of total N inputs from 2005–2008) (Eurostat, 2013b). Data on the use of sewage sludge in agriculture in Turkey is not available for the period 2007–2011. Yaman (2009) estimated that 420 kt (dry weight) of sewage sludge was used for agriculture in Turkey in 2006. Using the N content of sewage sludge of 1.3% reported by Bozkurt et al. (2001), this corresponded to only 0.4% of the mineral fertiliser N application used in the estimations. Therefore, the application of sewage sludge and other organic fertilisers was excluded from the calculations.

The net amount of N in manure imports/exports, withdrawals and stocks is calculated by subtracting manure exports and withdrawals from manure imports and stocks. Data show that the import and export of animal and plant manure for Turkey (TurkStat, 2013a) is negligible (less than 0.1%). Manure stock exchange is excluded in accordance with the Eurostat/OECD common guidelines (Eurostat, 2013b). In Turkey, some farm manure is used as combustible material for heating and cooking, but statistical data is not available on this. According to a study conducted in 1998, the amount of manure used for household heating was 191 kt (TurkStat, 2013b), which corresponds to about 0.4% of the manure used in estimations. Furthermore, the use of manure in household heating has steadily decreased in recent years. For our study we therefore assumed that all manure stocks were applied to soils.

Data on atmospheric N deposition are available from the European Monitoring and Evaluation Programme (EMEP) up to the year 2009. For 2010 and 2011, the average of the previous three years was used. N deposition was scaled to A_{ref} according to Eq. (1):

$$N_{\mathrm{dep}} = N_{\mathrm{dep,tot}} \times \frac{A_{\mathrm{ref}}}{A_{\mathrm{tot}}} \quad (1)$$

where $N_{\mathrm{dep,tot}}$ is the total atmospheric deposition of N in Turkey (kt N yr^{-1}), and A_{tot} and A_{ref} are the total land area and the reference area, respectively, used in the N-budget calculation.

Biological N fixation was calculated by multiplying the harvested area of leguminous crops by the coefficients of biological N fixation. N fixation of free-living microorganisms was excluded from the estimations in accordance with Eurostat/OECD common guidelines. The reasons for this exclusion are that the amount of N fixed by free-living soil bacteria is generally small, and the quality of the data available to estimate it is poor (Eurostat, 2013b).

N in crop and fodder production was estimated on the basis of harvest statistics (crops and harvested fodder) and the corresponding N contents. The amount of N exports in pastures and meadows was calculated based on areas, yields and share of grass consumed. National N content data were used for wheat, permanent grasslands, clover, barley, cotton seeds, grain maize, green maize, sugar beet, sunflower seeds, vetch, potatoes, and tomatoes (e.g. Sahin et al., 2006; Arslan and Tufan, 2011; Demir et al., 2006). The N removed by these crop products constitute 90% of the total N removed by crops and fodder in Turkey in 2011. For the N content of the other plant products, and the coefficients of biological N fixation for leguminous crops, the averages were used of EU Mediterranean countries (Spain, Italy, Portugal, Malta) for coastal Aegean and Mediterranean Regions, of Central European countries (Hungary, Slovenia, Slovakia) for Central Anatolia, Eastern Anatolia, South-East Anatolia and Black Sea Regions, and of EU Mediterranean countries and Central European countries for Marmara and Interior Aegean Regions (Eurostat, 2015). The productivity of meadows and grasslands was estimated according to OECD data (2011), which assumes that 70% of meadow and grassland produce is consumed. The N of crop residues removed was estimated using the methodology and coefficients of the IPCC (2006).

2.3. Estimation of minimum and maximum soil stock changes (GNB-minmax)

Data on N stock changes in agricultural soils in Turkey are not available. However, if $N_{\mathrm{input}} < N_{\mathrm{output}}$, either significant sources of N have been ignored, or soil depletion was responsible for at least the difference between output and quantified input. In such cases the GNB-Eurostat method leads to an overestimation of the NUE (Leip et al., 2011a). Using estimates of minimum and maximum soil stock changes (ssc) for each region, we quantified a range for the two indicators: NS_{minmax} and NUE_{minmax}.

We estimated a possible range of soil N stock changes $N_{\Delta\mathrm{soil}}$, on the basis of a possible range for NUE. In an experimental study, Karnez (2010) found a maximum NUE of 86.8% for wheat in the Çukurova Region of Turkey. This value was obtained according to the budget approach (N-outputs/N-inputs), and can be considered to be conservative (see also Leip et al., 2011b; Bouwman et al., 2005). We therefore assumed that all regions for which NUE_{eurostat} is higher than NUE_{max} = 85% suffer from soil N depletion. However, it is likely that the NUE of N released from organic material in the soil (N_{int}) is higher than the NUE of externally added N (N_{ext}). In the absence of data, we assumed that NUE_{int}, referring to the NUE of N released from soil biomass (crop residues, mineralised soil organic matter (SOM)), is 100%, allowing for a range between $NUE_{\mathrm{min,int}}$ = 90% and $NUE_{\mathrm{max,int}}$ = 100%. The uptake of N from mineralised crop residues is likely to be as efficient as the uptake from mineralised SOM, although this may already be factored into the NUE_{max} reported above. As an estimate of minimum NUE_{ext} we took the lowest NUE_{eurostat} (33%) estimated for a NUTS 2 region in Turkey ($\min\{NUE_r\}$) (Table 2).

The total plant N-uptake, N_{out}, is composed of the N that is taken up from both N_{int} and N_{ext} as given in Eq. (2):

$$N_{\mathrm{out}} = N_{int} \times \frac{NUE_{\mathrm{int}}}{100} + N_{\mathrm{ext}} \times \frac{NUE_{\mathrm{ext}}}{100} \quad (2)$$

Setting $-N_{\Delta\mathrm{soil}} = N_{\mathrm{int}}$ this gives:

$$N_{\Delta\mathrm{soil}} = \frac{1}{(NUE_{\mathrm{int}}/100)} \times \left(-N_{\mathrm{out}} + N_{\mathrm{ext}} \times \frac{NUE_{\mathrm{ext}}}{100}\right) \quad (3)$$

and minimum and maximum soil N-depletion rates are calculated according to Eqs. (4) and (5), whereby maximum losses are expected with minimum NUEs and vice versa (Table 2).

$$N_{\Delta\mathrm{soil,max}} = \frac{1}{0.9} \times \left(-N_{\mathrm{out}} + \frac{\min\{NUE_r\} \times N_{\mathrm{ext}}}{100}\right) \quad (4)$$

$$N_{\Delta\mathrm{soil,min}} = 1 \times (-N_{\mathrm{out}} + 0.85 \times N_{\mathrm{ext}}) \quad (5)$$

Considering minimum and maximum soil N-depletion rates (Eqs. (4) and (5)), we estimated minimum and maximum values of the NS by regions, and calculated NS_{minmax} as the mean value of this range.

2.4. Estimation of soil N stock change with a regression model (GNB-ssc)

A second method to estimate the GNB under conditions of soil N stock changes is based on the assumption that GNB-Eurostat gives reasonable results for regions, where $NUE_{\mathrm{eurostat}} < NUE_{\mathrm{max}}$, and that these data can be used to extrapolate the NUE and thus also the NS and $N_{\Delta\mathrm{soil}}$ for the remaining regions. According to Leip et al. (2011b), soil N stock accumulations are to be considered as a 'useful output' in a GNB, thus increasing the NUE, while soil N depletion leads to a reduction of N_{output} and consequently of NUE. N_{output} has regressed versus N_{input} for the regions and years analysed where $NUE_{\mathrm{eurostat}} < NUE_{\mathrm{max}}$ using a hyperbolic relationship (e.g. Willcutts et al., 1998; Mathews and Hopkins, 1999; Overman and Scholtz, 2002), as given in Eq. (6) (see Fig. 2). Regression parameters were fitted using the Excel Solver tool, minimising the root mean square (RMS). The model performance was found to be satisfactory based on an evaluation using the Nash–Sutcliffe efficiency coefficient and the ratio of the RMS to the standard deviation (Moriasi et al., 2007).

$$N_{\mathrm{output}} = \frac{149.5 \times N_{\mathrm{input}}}{150.5 + N_{\mathrm{input}}} \quad (6)$$

On the basis of Eq. (6), it is possible to estimate NUE_{ssc} and NS_{ssc} (Eqs. (7) and (8)) for all regions, including those for which soil N depletion has been observed or is likely to occur.

Table 2
Assumed values of the minimum and the maximum nitrogen use ficiencies (NUE).

	Minimum NUE	Maximum NUE
External N	$NUE_{\mathrm{min,ext}} = \min\{NUE_r\}$	$NUE_{\mathrm{max,ext}}$ = 85%
Internal N	$NUE_{\mathrm{min,int}}$ = 90%	$NUE_{\mathrm{max,int}}$ = 100%

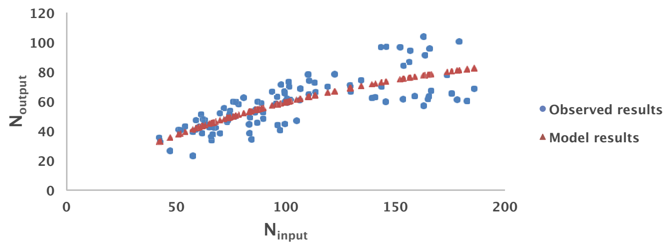

Fig. 2. Scatter plot diagram of N_{output} and N_{input} in NUTS 2 regions with $NUE_{eurostat} < NUE_{max} = 85\%$ in Turkey for the period of 2007–2011. Model performance indicators: Nash–Sutcliffe efficiency (NSE): 0.62; ratio of the root mean square error to the standard deviation of measured data (RSR): 0.61.

$$NUE_{model} = \frac{(149.5 \times N_{input})/(150.5 + N_{input})}{N_{input}} \times 100 \quad (7)$$

$$NS_{model} = N_{input} - \left[\frac{149.5 \times N_{input}}{150.5 + N_{input}}\right] \quad (8)$$

3. Results

3.1. NS and NUE estimations with the assessment of soil N stock changes

Fig. 3 shows NS calculated using the three approaches, i.e. GNB-Eurostat, GNB-ssc, and GNB-minmax. A table with all data used and results obtained is given in the Supplementary information. Agreement between GNB-Eurostat and GNB-ssc was generally good (p-value > 0.05 in a t-test). However, the difference was substantial for a few regions, with both higher and lower NS_{ssc} scores, which suggested that both soil N content depletion and accumulation occurred. For example, soil N was likely to have depleted in the regions of the Mediterranean (TR62 and TR63) (higher NS_{ssc}), while it was suggested to have accumulated in the regions in East Marmara (TR42) and in the western Black Sea (TR81) (higher $NS_{eurostat}$).

While GNB-minmax tended to predict higher discrepancies from GNB-Eurostat than GNB-ssc with regard to NS, both methods agreed for many regions (t-test p-value > 0.05). Deviations between NS_{minmax} and $NS_{eurostat}$ were generally positive for regions with smaller $NS_{eurostat}$ values (higher $NUE_{Eurostat}$ values), thus positioning $NS_{eurostat}$ at the lower end of the range estimated using the NS_{minmax} method. Deviations were negative in regions with high $NS_{eurostat}$ values.

The five-year (2007–2011) averages of NS_{ssc} and NUE_{ssc} in Turkey were 35 kg N ha^{-1} yr^{-1} and 62%, respectively. The lowest NS_{ssc} value was estimated at 31 kg N ha^{-1} yr^{-1} for the year 2008, and the highest at 36 kg N ha^{-1} yr^{-1} for the year 2011. Across the 26 NUTS2 regions, the five-year average NS_{ssc} ranged between 6 kg N ha^{-1} yr^{-1} in a region in Northeast Anatolia (TRA1) close to the northeastern border of Turkey, and 95 kg N ha^{-1} yr^{-1} in Istanbul (TR10) close to the northwestern border of Turkey. Correspondingly, the highest average NUE_{ssc} value was calculated for TRA1 at 81%, and the smallest NUE_{ssc} was calculated for TR10 at 46% (Fig. 4.).

The GNB-ssc and GNB-minmax methods estimated a change in average soil stocks in Turkey of +0.2 kg N ha^{-1} yr^{-1} (accumulation) and −4 kg N ha^{-1} yr^{-1} (depletion), respectively, over the five-year period. Both models estimated highest N soil accumulations in a region in East Marmara (TR42), with NS_{ssc} of 17 kg N ha^{-1} yr^{-1} and NS_{minmax} of 37 kg N ha^{-1} yr^{-1}. The highest N soil depletions were estimated by GNB-ssc in the Aegean Region (TR31) at −20 kg N ha^{-1} yr^{-1}, and by GNB-minmax in a region in Northeast Anatolia (TRA1) at −26 kg N ha^{-1} yr^{-1}.

Fig. 5 shows the contribution of N budget terms (inputs and outputs) for Turkey at the national level. The biggest contribution to N input was mineral fertilisers (47%), followed by manure (41%), atmospheric N deposition (5%) and biological N fixation (5%). The largest N output levels came from crop production (61%), followed by fodder production (31%) and crop residues removed (9%). $N_{\Delta soil}$ is disregarded in the contribution figures.

3.2. Comparison between the NS values of Turkey and EU countries

According to EU data in the Eurostat database (five-year average for 2007–2011) (Eurostat, 2013a), NS is highest in Cyprus, with 178 kg N ha^{-1} yr^{-1} due to high livestock density, and lowest in Romania, with −3 kg N ha^{-1} yr^{-1} due to the extensive production system. Turkey's average NS_{ssc} estimated over the period 2007–2011 was 35 kg N ha^{-1} yr^{-1}, which is lower than both the EU-28 average of 48 kg N ha^{-1} yr^{-1} (Fig. 6) and the average of OECD countries (excluding Chile, Estonia and Israel), for which the latest available data (average for 2007–2009) give a value of 63 kg N ha^{-1} yr^{-1} (OECD, 2013). Agricultural systems in Turkey are generally more extensive than in EU-28 countries, with smaller livestock densities. However, the NS data in the Eurostat and OECD databases were estimated ignoring possible changes in soil N stocks.

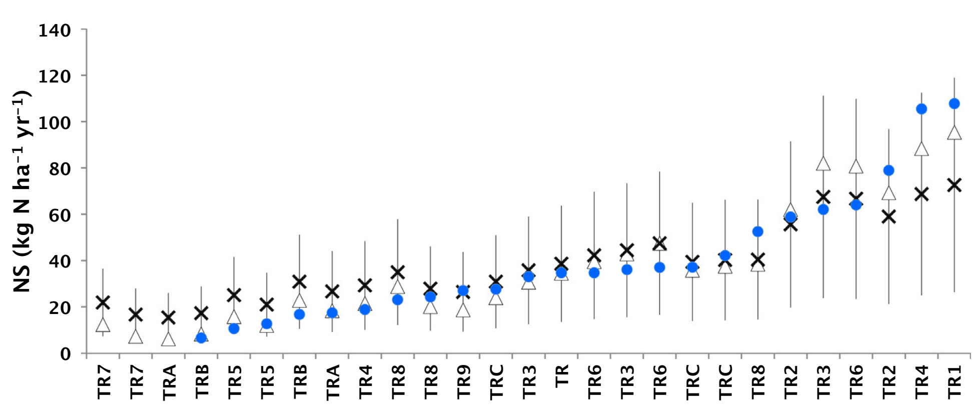

Fig. 3. $NS_{eurostat}$ (●), NS_{minmax} (X) and NS_{ssc} (Δ) for all NUTS 2 regions in Turkey. The lines indicate the ranges obtained with the GNB-minmax method. For explanation of abbreviations (regions) see the legend of Fig. 1.

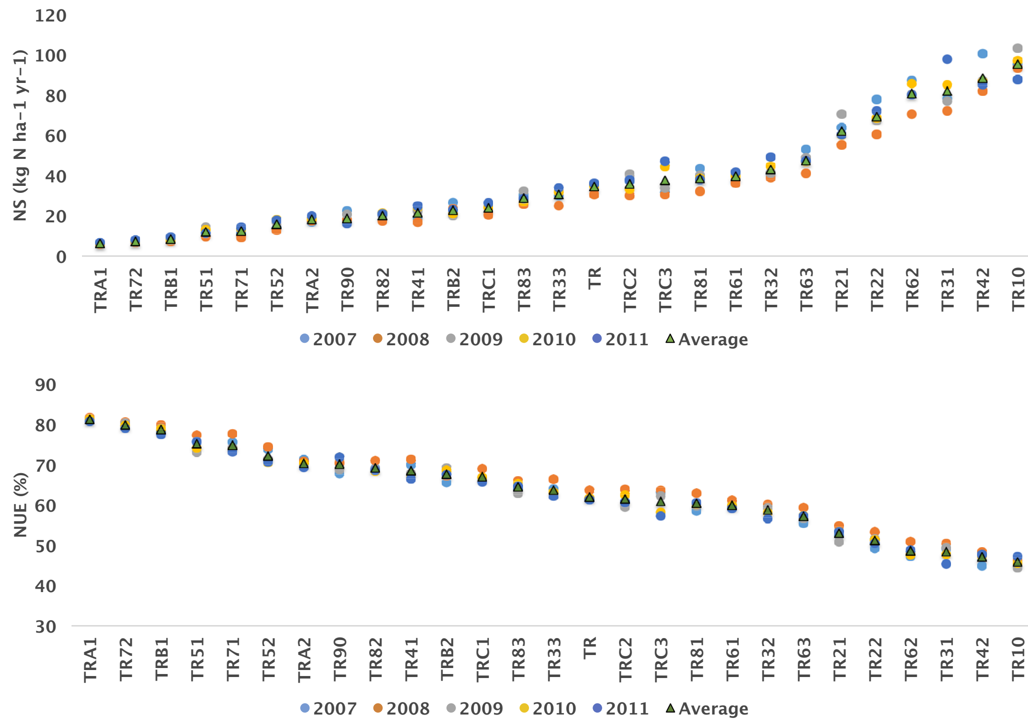

Fig. 4. NS_{ssc} and NUE_{ssc} for Turkey and its NUTS 2 regions for the years 2007–2011. For explanation of abbreviations (regions) see the legend of Fig. 1.

4. Discussion

The Eurostat/OECD method to estimate the GNB was developed under an assumption of no changes in soil N stock, due to a lack of data. Results obtained with GNB-Eurostat give NUEs that are higher than the NUE_{max} for three regions in Turkey (see Supplementary information). In such cases, the method warns that estimated NS and NUE indicators are not valid, as changes in soil N stocks are likely. Therefore, the Eurostat/OECD method needs to be extended to account for soil N stock changes.

In this paper, we used two different methods to improve N-efficiency indicators for Turkey: the first method (GNB-minmax) assumed a plausible range of NUE values for which a corresponding range of NS values could be derived. This range and the resulting average NS_{minmax} give reasonable but very rough NUE estimates for all regions, including those for which the $NUE_{eurostat} > NUE_{max}$. The second method (GNB-ssc) made use of those regions for which the NUE values estimated by GNB-Eurostat were below the assumed NUE_{max} (85%), and fitted the results with a hyperbolic curve (see Eq. (6)). Based on its application to the NUTS 2 regions in Turkey, we consider the results of this GNB-ssc model to be better estimates of the soil N stock change, NS and NUE indicators, as the model does not rely on the assumption of stable soil N stocks.

While the NS_{minmax} data consistently and predictably deviate from the $NS_{eurostat}$ at the low and high ends of the range of intensity across the NUTS 2 regions, the differences between NS_{ssc} and $NS_{eurostat}$ are less systematic. Interestingly, some regions with 'medium intensity' show large differences between NS_{ssc} and $NS_{eurostat}$, while NS_{ssc} and NS_{minmax} give very similar results.

NS and NUE values may vary significantly from one region to another, due to differences in the use of N inputs and outputs, farm practices, and environmental conditions (e.g. Bouwman et al., 2009; De Vries et al., 2011; Leip et al., 2011b). According to the GNB-minmax and GNB-ssc results, regional NS and NUE values of Turkey varied from 6 to 95 kg N ha^{-1} yr^{-1} and from 46% to 81%, respectively. Our data showed a strong correlation between NS and

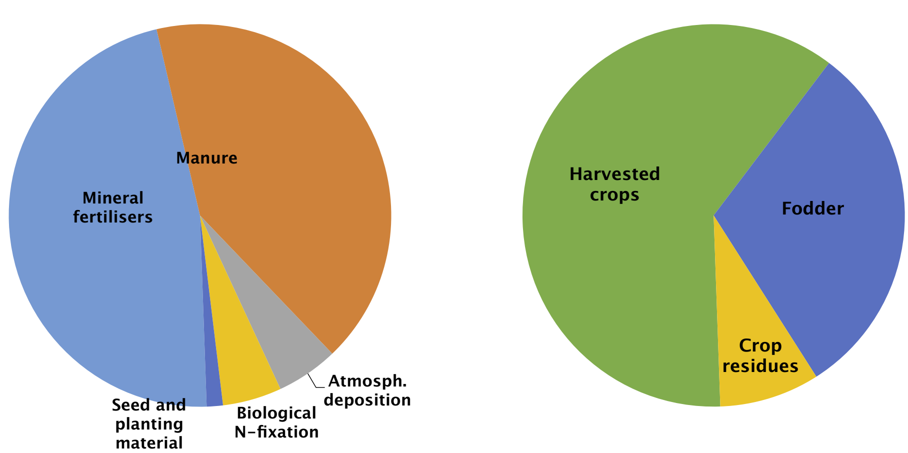

Fig. 5. Contribution of nitrogen budget terms to inputs (a) and outputs (b) for Turkey (all NUTS regions), averaged over the period 2007–2011

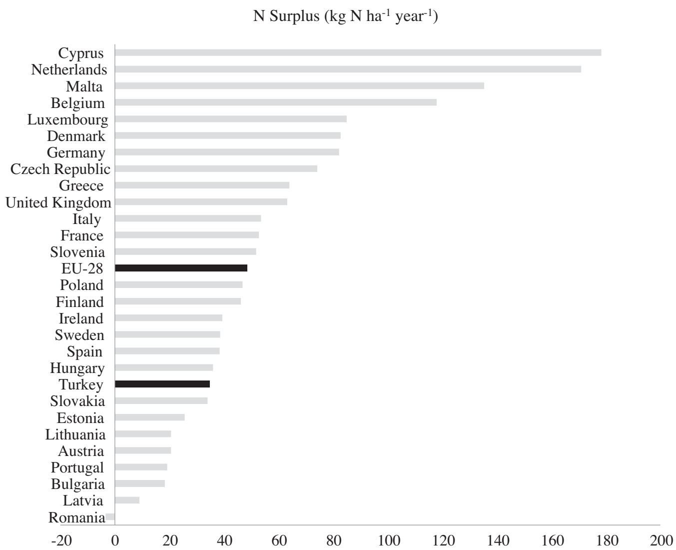

Fig. 6. NS_{ssc} for Turkey in comparison to national NS values reported by EU countries to Eurostat/OECD (Eurostat, 2013b). Data refer to the five-year average for 2007–2011.

NUE, with higher NS values found in regions of lower NUE and vice versa. We found the highest NS levels in those regions of Turkey with high levels of agricultural intensification in terms of mineral fertiliser usage and livestock density. On the other hand, in the interior regions of Turkey, where agriculture is extensive and has low N-input levels, NS is also low. The results indicate that soil N accumulation could be linked to the high density of cattle (e.g. TR81). Indeed, NS_{ssc} was lower than $NS_{eurostat}$ in all regions with high cattle density, with the exception of a part of the Aegean Region (TR31). The reason for this exception could be that conditions in this area are favourable to high N leaching rates (TEMA, 2014).

NS was lowest for almost all regions in 2008. This can be linked to low mineral fertiliser usage due to high mineral fertiliser prices and the economic crisis in Turkey during this year. It is difficult to validate the results due to the limited number of scientific studies on agricultural N budgets for Turkey. Karnez (2010) found an average NS of 45 kg N ha^{-1} yr^{-1} for wheat on a plain in the Mediterranean Region. This value is comparable to the average NS value of similar regions calculated in this study (52 kg N ha^{-1} yr^{-1}). Cetin et al. (2008) obtained a NS of 33 kg N ha^{-1} yr^{-1} for the same region, which lies clearly below the simulated values however still in a similar range.

Values for soil N stock change are reported for the Southeastern Anatolia Region of Turkey (3.3 kg N ha^{-1} yr^{-1}), calculated by multiplying the rate of organic carbon accumulation by an average C:N ratio (Sakin, 2010; Sakin et al., 2010). The result obtained for the reddish-brown soils commonly used for agriculture in the region is very close to the five-year average soil N stock changes of similar regions estimated in this study using GNB-ssc (3.2 kg N ha^{-1} yr^{-1}). On the national level, our results suggest an increase of the SOM level in Turkey for the period 2007–2011. While no studies have been carried out in Turkey against which we can compare, other studies found SOM accumulation in the croplands of western Germany for the period 1989–1998 (Nieder and Richter, 2000), in the agricultural land of southern Belgium for the period 1955–2005 (Goidts and van Wesemael, 2007), and in the agricultural land of Denmark for the period 1986–2009 (Taghizadeh-Toosi et al., 2014).

In most of Europe it is generally assumed that changes in soil N stocks are small compared to the input- and output levels of N, and the possible error due to ignoring them is thus small (Bouwman et al., 2006; Leip et al., 2014, 2011a,b; OECD, 2013; Velthof et al., 2009). However, NS estimates available from the Eurostat and OECD databases suggest that at least some of the low values reported could be linked to the mining of soil N. Extensive farming systems that do not have sufficient nutrient supply often face the problem of soil nutrient mining (Ozbek, 2014; Ebanyat et al., 2010; Mubiru et al., 2007; Stoorvogel et al., 1993; Vitousek et al., 2009), with consequences at the global scale (Jones et al., 2013) and for smallholder farmers (Musinguzi et al., 2013; Vanlauwe et al., 2010).

On the other hand, degraded soils can recover fertility by accumulating carbon and N through organic matter. Indeed, there is evidence that the average organic carbon content of Chinese cropland soils increased from 1980 to 2000 (Yu et al., 2009), and consequently the soil N content also increased, which is currently not reflected in estimates of NUE of Chinese croplands (Yan et al., 2014). So far, reliable efficiency indicators for such systems could only be derived at the regional scale if experimental data were available or process-based simulations were used (see e.g. Khalil et al., 2013; Li et al., 2005).

5. Conclusion

Changes in soil N stocks are likely to occur in several countries, including those for which estimates have been calculated based on the Eurostat/OECD GNB methodology. For those countries where changes in soil N stocks occur, existing N indicators at the regional or national levels are not reliable. Our approach to overcome this methodological deficiency could be applied to any country for which the main terms of the GNB are available at the regional level, and for which conditions cover sufficient variance. We believe that the approach presented here is a simple and feasible method that could be tested and applied in other countries, thus improving estimates of NUE and NS.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agee.2015.03.008.

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